Reflection and Absorption Contribution to the Multilayers Electromagnetic Shielding Effectiveness

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Abstract

EMI is necessary to protect electronic equipment from extraneous EM fields and to provide a controlled emission free environment for reliable functioning of electronic equipment. In this paper, the specific roles of reflection and absorption in determining the total shielding efficiency of three layer electromagnetic shielding, as a function of the frequency and the thickness of each layer is discussed. In particular, the reflection, the absorption and the shielding effectiveness of Tb11Fe86Cr3-polyacetylene doped electro chemically with 80% by weight iodine-copper laminatein the 2-18GHz frequency range have been presented.

Keywords

Multi-layer Structure; Electromagnetic Shielding; Reflection; Absorption; Shielding Efficiency

Introduction

The expansion of the electronic industry and the extensive use of electronic and electrical equipment in commercial, military, communications, computations, automations and other purposes have led to problems such as electromagnetic interference of electromagnetic devices and health issues (kuzananovic and al., 2009; Yildiz and al., 1998; Jing and al., 2005; ciesielska-Wrobel and al.2012; Schütze and al., 2008; Yang and al., 2007; Morari and al., 2001; Angelopoulos and al.,2011). Electromagnetic shielding is an efficient method to reduce the emission and improve the immunity of electronic equipment (Ciesielska-Wrobel and al., 2012; Sarto, 2003; Chung, 2000; Koldintseva and al., 2009). The ability of a shield is characterized by its shielding efficiency (Schütze and al., 2008; Jayasree and al., 2008; Jourdan and al., 2009; Frank and al., 2011; Al-Salah and al., 2009) which is a hat topic since shielding theory was developed. Due to their low specific mass, easiness of synthesis, the possibility to modulate easily the electronic properties from insulating to conducting materials through chemical process, low cost and processability, conducting polymers are required in many engineering applications, especially, for the design of microwave shielding to emureelectromagnetic compatibility and electromagnetic immunity (Angelopoulos and al., 2011; Al-Salal and al., 2009; wang and al., 2011; Dhawan and al., 2011; Ali and al.,2007). The shielding effectiveness of multilayer structure depends on the frequency, the angle of incidence polarization, the observation point where the transmitted fields are measured and the fundamental characteristics of each layer (σ_i, ε_i, μ_i, t_i) (Jourdan and al., 2009; Franck and al.,2011; Al-Salah and al., 2009; Ogunsola and al., 2006). In the present work, an electric analogy of a line of transmission and a mathematical formulation is developed for the appreciation of the reflectivity, absorptivity and shielding efficiency of a multilayered laminates. We examine the absorptivity, the reflectivity and efficiency of three layered laminate electromagnetic shielding.

Mechanisms of Shielding

The interaction's mechanisms of electromagnetic wave a material (Jourdan and al., 2009; Al-Salah and al., 2009) can be divided in three mechanisms: reflection, absorption and multiple reflections inside the shield materiel (fig. 1).Reflection is often the primary physical mechanism of shielding.

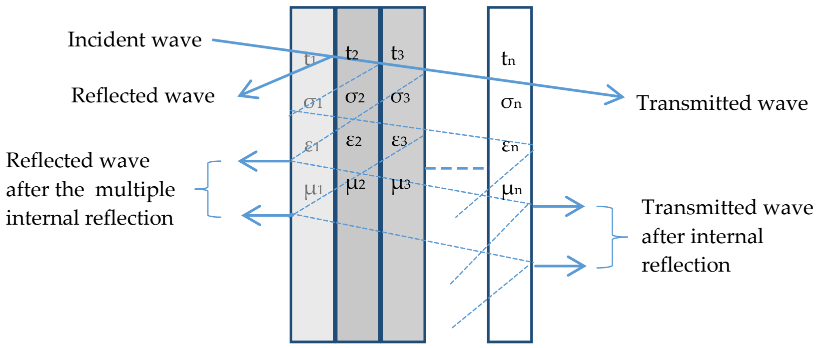

FIG. 1 SCHEMATIC SHOWING MULTILAYER ELECTROMAGNETIC SHIELDIN

To shield by reflection, the material must have mobile charge carriers (Morari and al., 2011; Al-Salah and al., 2009; Chung and al., 2001). The mechanism of reflection depends on the permittivity and conductivity of the sample (Al-Salah and al., 2009). The reflection at the interface between two media is related to the difference in characteristic impedance between the media (Morari and al., 2011; Morari and al., 2011; Chung and al., 2001).The second important mechanism is the absorption it depend on the thickness of the shield. For significant absorption of electromagnetic radiation (Morari and al., 2011; Chung, 2000; Jourdan and al., 2009; Al-Salah and al., 2009), the shield should have electric and/or magnetic dipoles that interact with the electromagnetic fields in radiations. The absorption loss (Morari and al., 2011; Al-Salah and al., 2009; Chung and al., 2001) is a function of the product $\sigma_r\mu_r$. Where, σ_r and $\mu_r$are, respectively, the relative electrical conductivity and the relative magnetic permeability.The last mechanism is the multiple reflections; it represents the internal reflection within the shielding material. This mechanism requires the presence of a large surface area or interface area. The loss due to the multiple reflections can be neglected when the distance between the reflecting surfaces is large, compared to the skin depth (Morari and al., 2011; Chung, 2000; Jourdan and al., 2009; Jourdan and al.,2009).

Electromagnetic interference shielding efficiency (SE) can be expressed as summation of the initial reflection loss (SE_R), absorption loss (SE_A) and internal reflection loss (SE_{IR}) (Morari and al.,2011; Al-Salah and al., 2009; Liu and al.,2007).

$$SE = SE_R + SE_A + SE_{IR} \quad (1)$$

Multilayer shield with n layer is modelled as a non-uniform transmission line which segmented into n sections (Fig. 2).

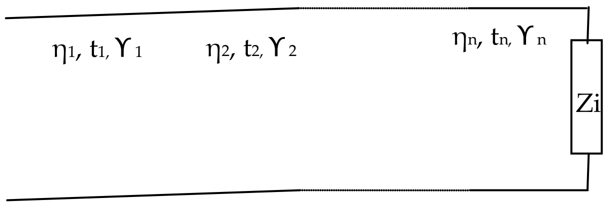

FIG. 2 CIRCUIT MODEL OF NON-UNIFORM TRANSMISSION LINE

Were η_i, γ_i and t_i are intrinsic impedance, propagation constant and thickness of ithsection (layer). Z_i is characteristic impedance of ithsection.

Results and Discussion

Reflectivity

The reflectivity of the incident electromagnetic wave normal to the planar multi-layer structure can be expressed as (Xiao and al., 2011; Feng and al., 2007).

$$R = 20\log(\Gamma) \quad (2)$$

Where $\Gamma$the overall reflection coefficient for a multi-layer interface [23,24] is given as:

$$\Gamma = \left|\frac{Z_i-\eta_0}{Z_i+\eta_0}\right| \quad (3)$$

Where: η_0 the free space intrinsic impedance =120π ohms and $Z_i$the characteristic impedance of ith layer (Shen and al.,2006) is given by

$$Z_i = \eta_i \frac{Z_{i-1}+\eta_i \tanh(\gamma_i t_i)}{\eta_i + Z_{i-1}\tanh(\gamma_i t_i)} \quad (4)$$

With η_i, γ_i and t_i are the intrinsic impedance, the propagation constant and the thickness of ithlayer(Raj and al., 2010)respectively.

$$\eta_i = \sqrt{\frac{j\omega\mu_i}{\sigma_i + j\omega\varepsilon_i}} \quad (5)$$

$$\gamma_i = \sqrt{j\omega\mu_i(\sigma_i + j\omega\varepsilon_i)} \quad (6)$$

Here, $\omega = 2\pi f$ is the angular frequency, $\mu_i = \mu_0\mu_{ri}$, $\varepsilon_i = \varepsilon_0\varepsilon_r$ and $\sigma_i = 2\pi f\varepsilon_0\varepsilon''$ are the permeability, the permittivity

and the conductivity ofi^{th} layer, respectively.

With: μ_0= $4\pi\times10^{-7}$ H/m and ε_0 = 8.854×10^{-12} F/m are the free space permeability and permittivity, respectively. $\mu_{ri} = \mu'_{ri}-j\mu_{ri}''$ and $\varepsilon_{ri} = \varepsilon'_{ri}-j\varepsilon''_{ri}$arethe relative permeability and permittivity of the i^{th} layer, respectively(Kent and al.,2007; Lee and al., 2008).

Figures 3, 4 and 5 illustrates the variations of reflectivity against the measured frequency range from 2 to 18GHz for the $Tb_{11}Fe_{86}Cr_3$-polyacetylene doped electro chemically with 80% by weight iodine-copper laminate for different thicknesses of microwave absorber ($Tb_{11}Fe_{86}Cr_3$), of conductive polymer (polyacetylene doped electro chemically with 80% by weight iodine) and conductor (copper) . It is observed that, the reflectivity decreased with increasing the frequency but decreased with increasing the thicknesses

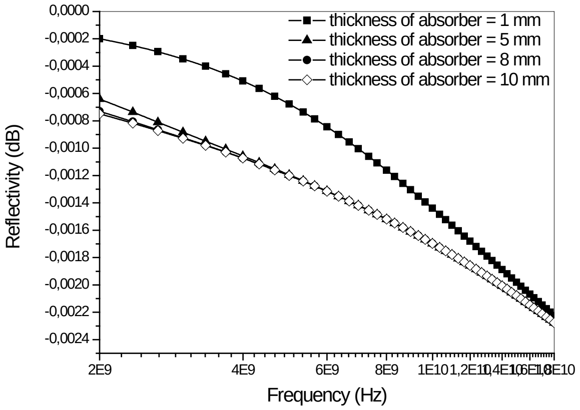

FIG. 3 THE VARIATION OF THE REFLECTIVITY AS AFUNCTION OF FREQUENCY OF $Tb_{11}Fe_{86}Cr_3$-POLYACETYLENE DOPED ELECTROCHEMICALLY WITH 80% BY WEIGHT IODINE-COPPER LAMINATE FOR DIFFERENT THICKNESSES OF MICROWAVE ABSORBER WITH 1.016mm, 0127mm THICHNESSES OF POLYMER AND COPPER RESPECTIVELY

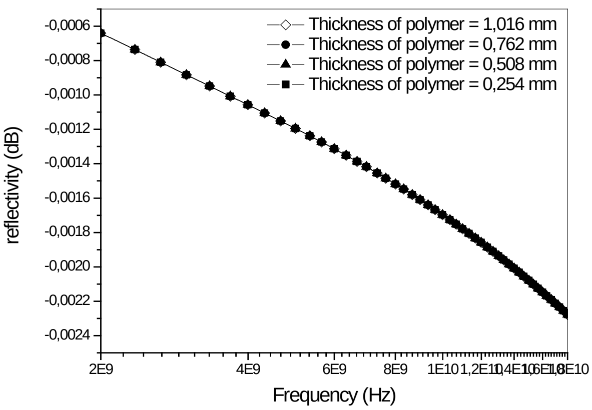

FIG. 4 THE VARIATION OF THE REFLECTIVITY AS A FUNCTION OF FREQUENCY OF$Tb_{11}Fe_{86}Cr_3$-POLYACETYLENE DOPED ELECTRO CHEMICALLY WITH 80% BY WEIGHT IODINE-COPPER LAMINATE FOR DIFFERENT THICKNESSES OF CONDUCTIVE POLYMER WITH 5mm,0.127 mm THICKNESSES OF MICROWAVE ABSORBER AND COPPER RESPECTIVELY

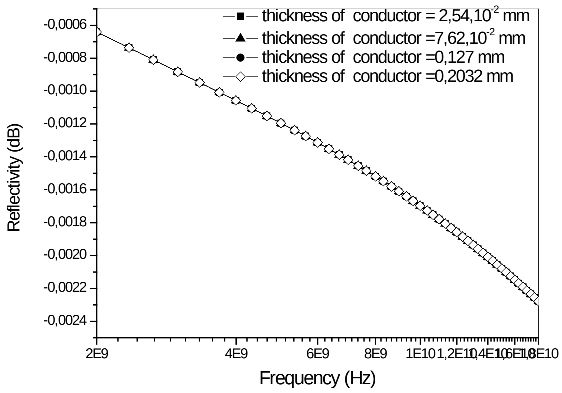

FIG. 5 THE VARIATION OF THE REFLECTIVITY AS A FUNCTION OF FREQUENCY OF$Tb_{11}Fe_{86}Cr_3$-POLYACETYLENE DOPED ELECTRO CHEMICALLY WITH 80% BY WEIGHT IODINE-COPPER LAMINATE FOR DIFFERENT THICKNESSES OF COPPER WITH 5mm AND 1.016 mm THICKNESSES OF ABSORBER AND POLYMER RESPECTIVELY

of microwave absorber and remains constant for the different thickness of the conductive polymer and conductor layer. As we all know, the improvement of reflectivity is primarily ascribed to the improvement of the entire conductivity of different layers. It also can be seen in Figure 3, increased the thicknesses of microwave absorber content decreased reflectivity from -1.99 10^4 to -2.29 10^{-3} dB over a frequency range 2–18 GHz and it can be seen in Figures 4 and 5, increased the frequency content decreased reflectivity from -6.31 10^{-4} to -2.28 10^{-3} dB and from -6.31 10^{-4} to -2.28 10^{-3} dB respectively over a frequency range 2–18 GHz.

Absorptivity

The absorptivity of 1 layer electromagnetic shielding is given by

$$A = 20\log_{10}[e^{-\gamma t}] \tag{7}$$

The absorptivity of n layer electromagnetic shielding is given by [31,32].

$$A = 20\log_{10}\left[e^{-(\gamma_1 t_1+\gamma_2 t_2+\gamma_3 t_3+\cdots+\gamma_n t_n)}\right] \tag{8}$$

$$A = 20\log_{10}[e^{-\gamma_1 t_1} e^{-\gamma_2 t_2} e^{-\gamma_3 t_3} \ldots e^{-\gamma_n t_n}] \tag{9}$$

$$A = 20\log_{10}[\textstyle\prod_{i=1}^{n} e^{-\gamma_i t_i}] \tag{10}$$

Or we can write the absorptivity by:

$$A = 20\textstyle\sum_{i=1}^{n}\log_{10}(e^{-\gamma_i t_i}) \tag{11}$$

Figures 6, 7 and 8 illustrates the variation of absorptivity against the measured frequency range from 2 to 18GHz for the $Tb_{11}Fe_{86}Cr_3$-polyacetylene doped electro chemically with 80% by weight iodine-copper laminate for different thicknesses respectively of microwave absorber ($Tb_{11}Fe_{86}Cr_3$), conductive polymer (polyacetylene doped electro chemically with

80% by weight iodine), conductor (copper). It is observed that, the absorptivity increases with increasing the frequency and the thicknesses, the improvement of absorptivity is primarily ascribed to the improvement of the entire conductivity of different layers. It also can be seen in Figures 6, 7 and 8 respectively increased the thicknesses of different layers content enhanced absorptivity from 1287.14 to 5397.97 dB, 1083.96 to 5371.74 dB and 472.49 to 7193.97 dB over a frequency range 2–18 GHz. This increment of the absorptivity is attributed mainly to the conductive network entire the molecular structure of different layers, which can effectively improve the electrical properties of different layers.

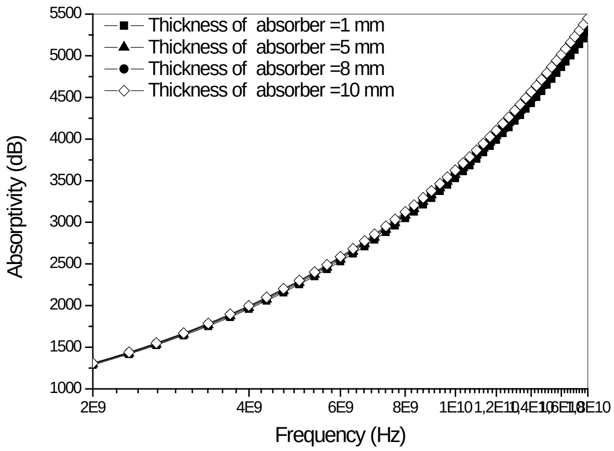

FIG. 6 THE VARIATION OF THE ABSORPTIVITY AS A FUNCTION OF FREQUENCY OF $Tb_{11}Fe_{86}Cr_3$-POLYACETYLENE DOPED ELECTROCHEMICALLY WITH 80% BY WEIGHT IODINE-COPPER LAMINATE FOR DIFFERENT THICKNESSES OF MICROWAVE ABSORBER WITH 1.016mm, 0127mm THICHNESSES OF POLYMER AND COPPER RESPECTIVELY

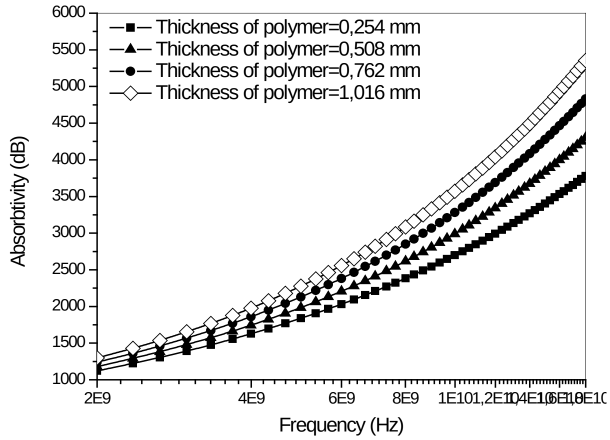

FIG. 7 THE VARIATION OF THE ABSORPTIVITY AS A FUNCTION OF FREQUENCY OF$Tb_{11}Fe_{86}Cr_3$-POLYACETYLENE DOPED ELECTRO CHEMICALLY WITH 80% BY WEIGHT IODINE-COPPER LAMINATE FOR DIFFERENT THICKNESSES OF CONDUCTIVE POLYMER WITH 5mm,0.127 mm THICKNESSES OF MICROWAVE ABSORBER AND COPPER RESPECTIVELY

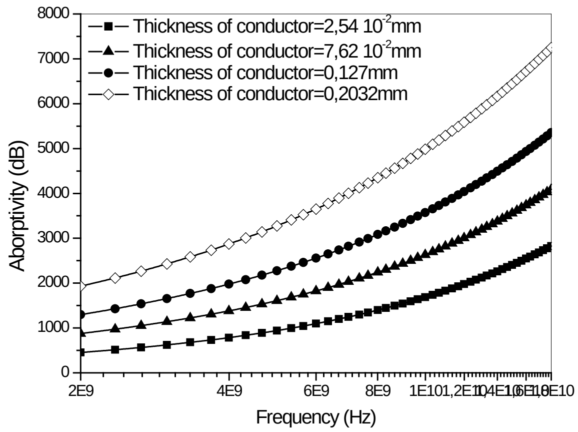

FIG. 8 THE VARIATION OF THE ABSORPTIVITY AS A FUNCTION OF FREQUENCY OF$Tb_{11}Fe_{86}Cr_3$-POLYACETYLENE DOPED ELECTRO CHEMICALLY WITH 80% BY WEIGHT IODINE-COPPER LAMINATE FOR DIFFERENT THICKNESSES OF COPPER WITH 5mm AND 1.016 mm THICKNESSES OF ABSORBER AND POLYMER RESPECTIVELY

Shielding Effectiveness

The shielding effectiveness (Raj and al, 2010; Zhang and al., 2008) of the n layer laminate electromagnetic shielding can thus be expressed in decibels as

$$\mathrm{SE(dB)} = -20\log_{10}(\mathrm{T}) \tag{12}$$

Where T is the total transmission coefficient [12, 34] across the laminate can thus derived to be

$$\mathrm{T} = \mathrm{p}\prod_{i=1}^{n}(1 - q_i e^{-2\gamma_i t_i})e^{-\gamma_i t_i} \tag{13}$$

Where p is the transmission coefficient across the interface at n boundaries [12,34] is given by

$$P = \frac{2\eta_0}{(\eta_n + \eta_0)}\prod_{i=1}^{n}\frac{2\eta_i}{(\eta_{i-1} + \eta_i)} \tag{14}$$

$q_i$is the interface reflection coefficient of i[th] layer is given as

$$q_i = \frac{(\eta_i - \eta_{i-1})(\eta_i - Z_{i+1})}{(\eta_i + \eta_{i-1})(\eta_i + Z_{i+1})} \tag{15}$$

Figures 9, 10 and 11 illustrates the variation of shielding effectiveness against the measured frequency range from 2 to 18GHz for the $Tb_{11}Fe_{86}Cr_3$-polyacetylene doped electro chemically with 80% by weight iodine-copper laminate for different thicknesses respectively of microwave absorber ($Tb_{11}Fe_{86}Cr_3$), conductive polymer (polyacetylene doped electro chemically with 80% by weight iodine),conductor (copper). It is observed that, the shielding effectiveness increases with increasing the frequency and the thicknesses for different layers, the improvement of shielding effectiveness is primarily ascribed to the improvement of the entire conductivity of different layers. It also can be seen in Figures 8, 9 and

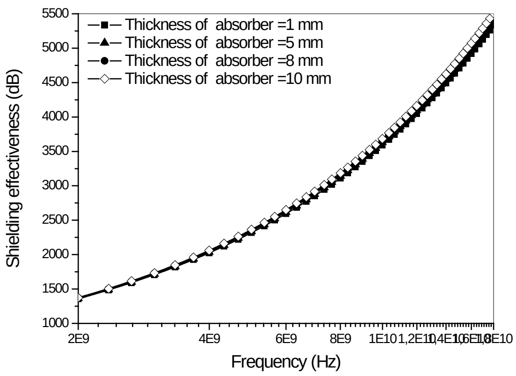

FIG. 9 THE VARIATION OF THE SHIELDING EFFECTIVENESS AS A FUNCTION OF FREQUENCY OF $Tb_{11}Fe_{86}Cr_3$-POLYACETYLENE DOPED ELECTROCHEMICALLY WITH 80% BY WEIGHT IODINE-COPPER LAMINATE FOR DIFFERENT THICKNESSES OF MICROWAVE ABSORBER WITH 1.016mm, 0127mm THICHNESSES OF POLYMER AND COPPER RESPECTIVELY

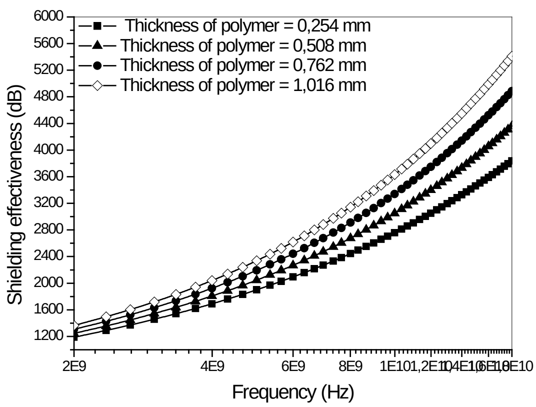

FIG. 10 THE VARIATION OF THE SHIELDING EFFECTIVENESS AS A FUNCTION OF FREQUENCY OF$Tb_{11}Fe_{86}Cr_3$-POLYACETYLENE DOPED ELECTRO CHEMICALLY WITH 80% BY WEIGHT IODINE-COPPER LAMINATE FOR DIFFERENT THICKNESSES OF CONDUCTIVE POLYMER WITH 5mm,0.127 mm THICKNESSES OF MICROWAVE ABSORBER AND COPPER RESPECTIVELY

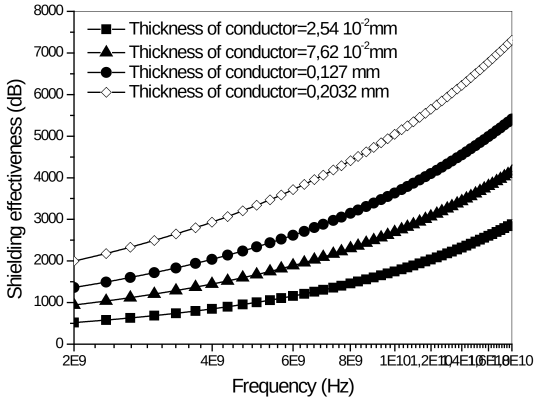

FIG. 11 THE VARIATION OF THE SHIELDING EFFECTIVENESS AS A FUNCTION OF FREQUENCY OF$Tb_{11}Fe_{86}Cr_3$-POLYACETYLENE DOPED ELECTRO CHEMICALLY WITH 80% BY WEIGHT IODINE-COPPER LAMINATE FOR DIFFERENT THICKNESSES OF COPPER WITH 5mm AND 1.016 mm THICKNESSES OF ABSORBER AND POLYMER RESPECTIVELY

10 respectively increased the thicknesses of different layers content enhanced shielding effectiveness from 1287.14 to 5397.97 dB, 1153.44 to 5389.11 dB and 500.28 to 7249.56 dB over a frequency range 2–18 GHz. This increment of the absorptivity is attributed mainly to the conductive network entire the molecular structure of different layers, which can effectively improve the electrical properties of different layers.

Conclusion

In this paper some general information on multilayer electromagnetic shielding is given. A theoretical aspect for the determination of reflection, absorption and electromagnetic effectiveness of three layer shielding are presented.

The presented results show that increase of absorber layer thickness increasing reflectivity. Increase of conducting polymer layer and copper layer thickness increasing absorptivity and electromagnetic shielding. This indicates a positive influence of absorber layer thickness on the reflectivity and a positive influence of conducting polymer layer and copper layer on both absorptivity and electromagnetic effectiveness. In the frequency range 2-18 GHz, the best shielding effectiveness was obtained for ($Tb_{11}Fe_{86}Cr_3$-PA doped with iodine-copper with 0,2032 mm thickness) sample, with an average value of 4518 dB. A close average value was obtained for ($Tb_{11}Fe_{86}Cr_3$-PA doped with iodine, 1,016 mm thickness-copper-copper) sample (3460 dB). The obtained results regarding the electromagnetic shielding effectiveness of the samples with different thickness of different layer show that for frequency between 2 and 18 GHz, the optimal sample for use as electromagnetic shielding are ($Tb_{11}Fe_{86}Cr_3$-PA doped with iodine-copper-copper with 0,2032mm thickness) sample.

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